PLACE OF PARTIAL CUTTING IN OLD-GROWTH STANDS OF THE DOUGLAS-FIR REGION

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INTRODUCTION

During the early 1930's, as use of the logging truck and tractor increased, a form of partial harvesting mature and overmature virgin stands developed in the Douglas-fir region (2). The cutting pattern varied from taking a few scattered high-grade trees per acre to clear cutting small areas. Partial harvesting caught on quickly because at that time only the high-grade trees could be logged at a reasonable margin of profit. This was a new procedure in the Douglas-fir type, and its effect on the future stand was unknown (7).

Thinning and stand-improvement cuttings had long been accepted practices in young and thrifty stands of many forest types with intolerant species, including Douglas-fir (3). But in the 1930's, the single-tree system of cutting was advocated for virgin forests of mature or even decadent old-growth Douglas-fir virgin forests with hemlock, true firs, and cedar in mixture and in understory. Sometimes these mixture species predominated. The system cannot be called a thinning in these overmature stands since thinning commonly applies to young, or at least thrifty stands. Neither can it be called selection cutting, since true selection cutting consists of harvesting the ripe trees from an all-aged forest of tolerant species with reproduction continuously replacing the trees cut (1). Since it is neither a true thinning nor an individual tree selection cutting, the partial removal of trees from the stand, when mentioned in this report, will be called partial cutting (4).

Original proponents of the system called it selective timber management in the Douglas-fir region (5). It embodied successive light cuts taking out the better trees mostly over 40 inches d.b.h. It also assumed that smaller trees would continue to move up into the larger diameter classes, and that gradually an all-aged forest

would develop. The system, as originally described, made occasional reference to clear cutting in small groups or spots if satisfactory restocking did not occur after several light tree-selection cuts. But the first stages of the cutting system did not turn out as anticipated, and time had not permitted the later phases of the system to get beyond the "theory" stage before logging methods changed.

This system was thought justified, first, by the high cost of constructing a road system into the areas, and second, by prospects for a rising market for the low-value elements of the stands. As markets and transportation improved, more emphasis was given to removal of high-risk, inferior, and dead trees as well as the good trees in the stand; but the cut still included only merchantable trees from the largest and oldest class, mostly Douglas-fir.

Slash burning following partial cuts proved impractical, and it soon became evident that cutting more than a third of the stand would leave an intolerable slash hazard and would magnify windfall risk. As partial cutting got under way in the region, the upper limit of cut became rather automatically set at about one-third of the gross volume--a few cuts were heavier, and many were lighter (4).

PURPOSE AND SCOPE OF THE STUDY

Although based largely on theory, the partial-cutting system quickly gained momentum and posed problems for which answers were not available. For one thing, a tree-selection system presupposes an all-aged forest, but it was not known if partial cutting would bring about an all-aged forest with Douglas-fir in the stand. Perhaps partial cutting would speed up natural transition to a climax forest of more tolerant but less valuable species and eliminate the Douglas-fir. This transition takes place as natural stands grow old in the absence of complete destruction of stands by fire, insects, or disease (4, 6).

Then too, it was not known if overcrowded and overmature stands could be rejuvenated by partial cutting and growth of the reserve stand increased. And what effect would this type of cutting have on the kind and quality of material produced? Some claimed that partial cutting would prolong the life of the remaining stands of old-growth Douglas-fir, extending the cutting period of high-grade clear material and plywood logs. Others claimed it would more quickly skim the cream of this material from the old-growth stands.

Much other information was needed. For example, could partial cutting be done on steep, rough topography? Also, how much logging damage would be done to reserve trees, and how would it affect tree vigor and decay entrance? Because conditions within this forest type are extremely variable, recommendations were needed to indicate the conditions under which partial cutting was or was not likely to succeed. Only field tests and demonstrations could supply all the wanted facts.

Accordingly, a study was started in 1935 to record the effect of such partial cutting as was being done on national-forest timber sales. Starting in advance of cutting, the study was designed to record, by species: The original stand, cut, logging breakage or injury, subsequent windfall, other mortality, and growth of the reserve stand; also change in stand composition, including incoming regeneration.

The system was recommended and applied to spruce-hemlock and upper slope mixtures as well as to pure Douglas-fir stands. Therefore, study areas were set up in the subtypes as well as in the major type of the region.

Sample plots were established from year to year as cutting areas became available, until 17 areas had been sampled totaling 76 acres of tagged, measured, and remeasured trees. Fifteen of the areas were in typical old-growth stands distributed from Darrington, Washington, on the north to Oakridge, Oregon in the south. An additional group was located in Port-Orford-cedar, and one, the seventeenth, in a two-aged spruce-hemlock stand in the fog belt from which many large, scattered, old-growth trees had previously been cut.

Because it was impracticable to distribute a large number of small plots over a large timber-sale area on the national forests without interfering with the operation, no effort was made to get a true random sample of entire cutting areas. Instead, a representative part of an area was selected, and a solid block of sample plots with all trees tagged was put in. This concentration of plots minimized interference with logging operations. Existing timber-sale contracts made no provisions for leaving portions of areas undisturbed; therefore, check areas could not be set up for statistical comparison of growth and mortality in uncut and partially cut areas. Because of the design of the study, a statistical analysis was not made for this report. Instead, the areas were treated as case studies, the results averaged, and general conclusions drawn from these averages.

The stands varied in stand composition and condition and in age from 150 to 600 years. Size of sample in a locality varied from three to fifteen 1-acre plots; these were in one or more separate 3- to 6-acre blocks. If there was a marked difference in age or stand structure on parts of a large area in a locality, separate blocks of sample plots were put in. Douglas-fir was present on all but one area, which had a Sitka spruce stand. The Douglas-fir was even aged and usually in the oldest age class present. Some of the more tolerant associates were equally old, but most were younger and made up a well-developed understory. This understory was important in most of the reserve stands as it usually was not taken in the early cuts.

All of the study areas have had a 5-year remeasurement for growth and more frequent mortality checks. Ten of the areas have had the 10-year remeasurement. In addition, there is a record of a "second cut" and a "third cut" on one area, and on another the permanent plots were supplemented by temporary plots to give more complete coverage.

REGIONAL AVERAGE OF RESULTS OF PARTIAL CUTTING

Although the stands varied in age, density, composition, and condition, 15 of the 17 study areas were sampled in a similar manner and were sufficiently similar otherwise to permit averaging for volume cut or destroyed, mortality from windfall or other causes, logging injury, and growth.

The gross volume [1/] of stands varied from 93,000 to 177,000 board feet per acre, averaging 137,000 (tables 1 and 2). The cut varied from 17,000 to 86,000 board feet per acre, and averaged 50,000 or 36 percent of the stand.

1/ The term "gross volume" as used in this report means the total volume of all living trees with no deduction for decay or other defect. Some decay was present in all stands and sometimes approached one-half of the stand volume, but there was no way to evaluate it accurately in this study. All volumes are given in board feet Scribner rule.

Table 1.--Original stand and cut with annual mortality, gross growth, and net increment during first five years in old-growth Douglas-fir stands.
(Per-acre values are given in number of trees and Scribner volume--15 areas comprising 64 acres.)

Sample plot designation	Original stand		Cut or destroyed		Annual mortality and gross growth: Mortality: Windfall		Annual mortality and gross growth: Mortality: Other		Annual mortality and gross growth: Gross growth		Annual net increment		Reserve stand 5 years after cutting	
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. Ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Willamette National Forest														
P.S.P. No. 6	79.3	98,032	25.6	40,256	0.04	11	.58	205	0.24	207	-0.38	- 9	51.8	57,730
7	52.4	158,966	15.1	54,309	.06	79	.52	837	.20	256	- .38	- 660	35.4	101,358
8	46.2	121,795	9.2	39,498	.54	274	.30	382	.04	212	- .80	- 444	33.0	80,077
9	99.3	147,321	33.7	53,595	.06	62	.20	37	--	308	- .26	209	64.3	94,772
Mt. Hood National Forest														
P.S.P. No. 6	89.3	92,733	26.7	31,440	.32	357	.40	254	--	371	- .72	- 240	59.0	60,092
7	82.6	93,898	16.3	17,128	.20	69	.66	552	--	684	- .86	63	62.0	77,085
8	57.6	160,945	12.3	40,832	--	--	.06	16	--	317	- .06	301	45.0	121,616
9	84.5	108,018	8.0	20,769	--	--	--	--	.10	594	.10	594	77.0	90,218
Mt. Baker National Forest														
P.S.P. No. 2	137.3	109,126	39.7	43,279	.24	344	.56	299	--	837	- .80	194	93.6	66,816
Olympic National Forest														
P.S.P. No. 17	84.9	157,301	18.5	42,932	2.50	6,916	--	--	--	648	-2.50	-6,268	53.9	83,031
18	58.0	102,588	10.4	61,713	.80	337	.44	371	.52	659	- .72	- 49	44.0	40,630
19	53.2	127,400	3.4	21,721	.52	659	.60	683	.40	1,172	- .72	- 170	46.2	104,827
20	31.0	170,404	4.4	58,938	.40	3,010	.64	572	.24	501	- .80	-3,081	22.6	96,060
21	43.4	176,964	6.4	86,141	.56	3,154	2.08	2,185	.20	517	-2.44	-4,822	24.8	66,715
22, 23, and 24	47.7	162,786	12.0	72,803	.06	232	.68	984	--	435	- .74	- 781	32.0	86,080
Weighted average	67.6	136,765	15.8	49,887	.42	1,099	.58	590	.12	535	- .88	-1,154	47.4	81,106

Table 2.--Reserve stand 5 and 10 years after cutting, annual mortality, gross growth, and net increment during second five years in old-growth Douglas-fir stands. (Per-acre values are given in number of trees and Scribner volume--10 areas comprising 47 acres.)

Sample plot designation	Reserve stand 5 years after cutting		Second five years: Annual mortality and gross growth: Mortality: Windfall		Other		Growth:	Annual net increment		Reserve stand 10 years after cutting	
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Willamette National Forest											
P.S.P. No. 6	52.7	57,176 [1]	0.44	132	0.14	71	267	0.30	64	54.2	57,494
7	36.3	102,123	.46	1,619	.06	415	229	.14	-1,805	37.0	93,098
9	62.0	92,141	.06	13	.14	78	419	- .08	328	61.6	93,777
Mt. Baker National Forest											
P.S.P. No. 2	93.6	66,816	.70	80	1.30	466	971	-1.54	425	85.9	68,943
Olympic National Forest											
P.S.P. No. 17	53.9	83,031	.24	661	.14	102	787	- .34	24	52.2	83,151
18	44.0	40,630	2.90	2,615	.62	565	420	-3.02	-2,760	28.9	26,830
19	46.2	104,827	.20	308	.24	409	988	--	271	46.2	106,180
20	22.6	96,060	.20	1,033	.56	1,738	341	- .28	-2,430	21.2	83,908
21	24.8	66,715	.04	230	.60	905	356	- .32	- 779	23.2	62,820
22, 23, and 24	33.5	82,521	.08	276	.24	702	724	.32	- 254	35.1	81,253
Weighted average	44.0	79,503	.46	627	.40	608	583	- .38	- 652	42.1	76,242

[1] After the first 5 years there was some adjustment in plot boundaries and numbered trees. For that reason, the first 2 columns in the second 5-year record do not always check with the last 2 columns.

Growth and Mortality, First Five Years After Logging

Some acre plots of each study area and 5 entire areas of the 15 showed a net growth per acre for the 5-year period. Volume loss varied greatly between areas. Annual growth of trees alive at the end of the first 5 years after cutting averaged 535 board feet per acre (table 1). But mortality from windfall and other causes on 10 areas was so great that total loss more than offset growth. The average total mortality for all areas was 1,689 board feet per acre per year. Hence, the 15 study areas had a net loss of 1,154 board feet per acre per year for the first 5-year period after cutting. Heavy losses on three areas raised the average severalfold.

Growth and Mortality, Second Five Years After Logging

Some areas stabilized within the first 5 years following logging, but others did not (table 1). Records are available for the second 5-year period on 10 of the 15 areas (table 2). Two of these 10 areas showed a net gain for both the first and second 5-year periods, and an additional 3 areas (making a total of 5) apparently stabilized and showed a net growth during the second 5-year period. The remaining 5 areas continued to show a net loss. The only evidence that losses would eventually subside was the fact that more areas showed a net gain during the second period than during the first period. Annual growth of trees alive at the end of the second 5 years after cutting averaged 583 board feet per acre. On 10 areas, the second 5-year record showed an average annual loss of 652 board feet per acre.

Growth and Mortality for Entire Ten-Year Period After Logging

The annual net loss for the first 5 years was 1,154 board feet and for the second 5 years was 652 board feet, making a weighted average of 941 board feet per acre per year for the first 10 years after logging. The weighted average current growth rate of trees that remained alive for the same period was 555 board feet per acre per year. 2/ If all mortality ceased (and there is no reason to believe that it will), it would still take more than 16 years at the

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2/ Since records for the same number of areas were not available for the first and second 5-year periods, weighted averages were used for 15 areas in the first 5 years and 10 areas in the second 5 years.

current rate of gross increment to regain what was lost in the preceding 10 years. In other words, 26 years after cutting, the average of all stands would contain about the same volume of timber as they had when the first cutting operation was completed. The process is apparently something like this: After cutting, a few stands put on net volume growth from the beginning, some make no net growth, some gradually lose volume, and others go to pieces entirely; the average after 10 years is still a net loss.

Growth of Reserve Trees Before and After Partial Cutting

All areas showed gross growth after logging, but were individual trees actually released by cutting, and was growth accelerated in the reserve stand? To answer these questions, 769 trees were increment bored on the areas listed in tables 1 and 2. Growth measurements were made for the 10 years before cutting and the 10 years after (table 3). Trees were selected at random in all size classes and from all species present.

As the age and size of the individual tree increased, response to cutting decreased. Douglas-fir usually belonged to the oldest age class, and about two-thirds of these trees showed either a decline in growth rate or an unchanged rate after cutting. The same was true for Sitka spruce where it was present. The reverse was true of hemlock, cedar, and silver fir, which made up most of the trees in younger age classes and smaller diameters in the understory; about three-fifths of these trees showed accelerated growth. Of the 769 trees of all species, half showed increased growth, the other half a decreased or unchanged growth rate. Sometimes severe logging injury was the apparent cause of lack of accelerated growth; other times, it was evident that the trees were not released by the cutting. And sometimes the trees appeared too overmature and decrepit to respond. It was not possible to correlate increased growth on individual trees with average growth per acre after cutting, but it was apparent from core measurements that acceleration in growth rate on half of the trees probably about compensated for the decline in growth rate on the rest. Windfall and other losses following cutting affected trees making accelerated growth and others alike.

Table 3.--Effect of partial cutting on diameter growth[1/] of individual trees

Species	Total trees increment bored	Increased diameter growth	No change	Decreased diameter growth
	Number of trees			
Douglas-fir	229	72	47	110
Western hemlock	354	214	31	109
Western redcedar	81	46	10	25
Silver fir	31	21	2	8
Sitka spruce	74	29	0	45
Total number	769	382	90	297
Percent of total	100	50	12	38

1/ Based on radial growth 10 years before and 10 years after cutting determined by increment boring.

Logging Injury to the Reserve Stand

Logging injury to the reserve stand is important not only because of the physical damage to the trees, but because the scars are ports of entry for wood-decaying fungi. The nonresinous species, such as hemlock, true firs, and to some extent Sitka spruce, are very susceptible to decay. Since they occur in the understory and in mixture with Douglas-fir in the region, logging injury to them is of more than usual significance (figures 1, 2, 3, and 4). A separate study of decay entrance in these species shows that 3 to 15 years after injury more than 63 percent of the logging scars had decay in them (9).

Injuries in this study consisted of broken tops and damage to the trunk, base, or roots of the tree. Many trees had more than one type of injury. The injury to the reserve stands in the 15 areas that are shown in table 1 varied from 17 to 50 percent, and averaged 34 percent of the trees. Sometimes the injuries were slight, but other times they were great enough to retard growth or kill the tree. While the significance of accelerated decay following logging injury was recognized, volume of decay was not calculated and must be considered as an undetermined amount over and above other losses shown in this report.

Causes of Loss and Comparison with Loss in Undisturbed Stands

Losses were not confined to any single species, crown class, or locality. Because of variation in stand and exposure on the different areas, no direct relationship was found between percent of cut and windfall losses.

Windfall was the greatest single cause of loss (tables 1 and 2). It happened at a time when similar losses were not occurring in nearby virgin stands, although some windfall in virgin stands had occurred earlier. In the first 5 years after logging, windfall losses on the plots were practically double the mortality from all other causes combined. Some loss occurred on 13 of the 15 areas for which the first 5-year record was available; the average annual windfall loss for the period was 1,099 board feet per acre per year.

Windfall losses declined in the second 5 years to 627 board feet per acre per year and about equalled mortality from other causes on 10 of the areas where the second 5-year record was available. There was some loss on all 10 of these areas. In general, the

Figure 1.--Widely scattered old-growth Douglas-fir in a dense understory stand of hemlock and silver fir just under commercial size. Large trees cannot be removed without serious injury to reserve. They should not be cut until understory trees reach commercial size and injured trees can be salvaged. (F.S. Photo 429812)

Figure 2. --Understory trees in this stand were mostly of good form and commercial size. Injured trees were cut and salvaged when large, old Douglas-firs were cut. (F.S. Photo 429807)

Figure 3.--Partial cutting in this type of forest left in the reserve stand decrepit, poorly formed, understory hemlock and decadent old-growth hemlock and Douglas-fir. (F.S. Photo 437585)

Figure 4. --Removing large trees from a dense understory or young-growth stand cuts deep skidroads, tears the roots and injures the base of many reserve trees. (F.S. Photo 429784)

losses were greatest in the stands which had the heaviest original volume, but results are not entirely consistent (tables 1 and 2). Although actual measurements are not available, it is known that windfall losses have occurred on these plots since the 10-year period, to the extent that several areas have had to be clear cut for salvage. The data reveal no way to predict where windfall losses will strike, or how to avoid them except possibly by lighter cuts.

Losses from causes other than windfall have remained somewhat constant, about 600 board feet per acre per year throughout the 10-year period, and about equal the growth (555 board feet) of trees left alive. Exact causes of these losses have been difficult to isolate and identify. Even bark beetle attack, the most common cause, is difficult to identify as the primary and only cause of mortality. Bark beetle attack usually occurred from 1 to 2 years after cutting, and was commonly most severe when large chunks of unmerchantable material were left strewn over the forest floor. One group of plots near Cushman Lake, Washington, showed a heavy loss from beetle attack. Logging injury, sunscald, and exposure are other causes that contributed to loss. Often no cause could be ascribed.

As previously stated, a direct comparison of losses with and without partial cutting was not obtained because it was not feasible to establish check plots to measure normal losses in uncut virgin stands. However, records of mortality in untouched, old-growth stands are available from other sources.

Sample plots in a declining 350-year-old Douglas-fir stand in the Wind River Natural Area showed a periodic annual mortality of 759 board feet per acre and a net growth of 8 board feet per acre per year. This was for the 6-year period of 1947 to 1953, of which 1949 and 1951 were severe windfall years (8).

During the 5-year period, 1948 to 1952, forest survey crews in several counties of western Washington and Oregon estimated mortality occurring during 5 years previous to plot examinations. 3/ Gross growth of merchantable trees was determined by increment borings on 169 1/5-acre plots, and 5-year mortality was estimated on 1,042 plots (table 4). This table, which gives results by age classes starting with age 180, shows an average gross growth of 500 board feet, a mortality of 345 board feet, and a net growth of 155 board feet (Scribner rule) per acre per year.

3/ Extract from forest survey file records. Robert B. Pope. May 1955.

Table 4.--Growth and mortality in undisturbed old-growth stands of the Douglas-fir region

Age class, years	Average vol./acre bd. ft.	Gross growth bd. ft./ acre per year	Mortality bd. ft./acre per year	Net growth bd. ft./ acre per year
180 - 250	52,106	516	280	236
260 - 350	65,128	410	351	59
360+	117,481	740	616	124
Uneven	47,325	431	248	183
Average	75,212	500	345	155

For the purpose of comparison with study figures, these survey figures may be considered as a conservative estimate of mortality and an optimistic estimate of growth. This is true because in the original stand estimate the forest survey made a deduction for decay and considered only merchantable trees, while the figures used in this study made no deduction for decay and do include totally cull but living trees.

The foregoing records of mortality in undisturbed stands show a net gain of 8 board feet per acre per year for the natural area, and 155 board feet net gain for the survey estimate, compared with a weighted average annual volume loss in this study of 941 board feet per acre for the 10-year period following partial cutting. On the basis of these comparisons there appears to be evidence that partial cutting not only failed to restore overmature Douglas-fir stands to a condition of thrift, but resulted in significant loss.

RESULTS OF PARTIAL CUTTING UNDER SPECIFIC STAND CONDITIONS

The regional averages (tables 1, 2, and 3) show the effect of the treatment on the type as a whole, but these averages often obscure many of the effects of partial cutting in certain stands. These more detailed effects become apparent from the history of plots in a specific forest type, a stand condition, or a locality, and show in more detail the effect of partial cutting. Discussion of such records summarized by species for similar types or conditions follows:

West Central Oregon Cascade Forests

Four groups of sample plots located above Oakridge, Oregon, are Willamette National Forest permanent sample plots Nos. 6, 7, 8, and 9, representing four distinct stand conditions occurring in this general locality. Except for plot No. 9, they are typical of the more decadent stands on the dry sites in the southern Oregon Cascades (table 5).

A Two-Age-Class Stand

Plot No. 6 represents a Site IV stand of overmature old-growth Douglas-fir that was heavily burned some 85 years ago. The stand was completely killed in some spots and partially killed in others. Some of the largest openings regenerated to young Douglas-fir in the center and to hemlock and cedar around the edges. At the time of partial cutting these young Douglas-firs were below merchantable size, and none were intentionally cut. Trees cut were all scattered old growth. Where the old stand had not been completely destroyed by fire 85 years ago, it was so reduced in density that a heavy understory of hemlock and cedar had developed. Logging damage was heavy in this residual stand when selected large old-growth trees were taken out. The site was flat and dry, and the hemlock that had developed as an understory was of very poor quality, often being of poor form and partially decadent before reaching merchantable size. The stand before cutting averaged 98,000 board feet gross volume per acre, mostly in the large old-growth Douglas-firs. About 10 old-growth Douglas-fir trees to the acre, with a total volume of 37,000 board feet, were cut in 1939.

Sixteen hemlock and cedar trees in the 10-inch diameter class with a volume of 3,000 board feet per acre were destroyed by the logging operation; in addition, about 40 unrecorded trees under

Table 5.--Original stand and cut, with annual mortality, gross growth, and net increment during first and second 5 years in West Central Oregon Cascade areas. (Per-acre values are given by species in number of trees and Scribner volume.)

Plot location and species	Original stand		Cut or destroyed		First 5 years: Annual mortality and gross growth: Mortality: Windfall		Other		Gross growth		Annual net increment		Reserve stand 5 years after cutting	
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Willamette N. F. - No. 6														
Douglas-fir	19.7	76,958	9.7	37,038	--	--	0.04	8	--	26	-0.04	18	9.8	40,009
Western hemlock	37.7	11,708	6.7	1,168	--	--	.44	99	0.24	123	- .20	24	30.0	10,659
Western redcedar	21.9	9,366	9.2	2,050	0.04	11	.10	98	--	58	- .14	- 51	12.0	7,062
Total	79.3	98,032	25.6	40,256	0.04	11	0.58	205	0.24	207	-0.38	- 9	51.8	57,730
Willamette N. F. - No. 7														
Douglas-fir	22.0	132,579	8.7	52,706	--	--	0.06	375	--	85	-0.06	- 290	13.0	78,424
Western hemlock	26.7	21,143	5.7	1,486	--	--	.40	347	0.20	156	- .20	- 191	20.0	18,701
Western redcedar	3.7	5,244	.7	117	0.06	79	.06	115	--	15	- .12	- 179	2.4	4,233
Total	52.4	158,966	15.1	54,309	0.06	79	0.52	837	0.20	256	- .38	- 660	35.4	101,358
Willamette N. F. - No. 8														
Douglas-fir	43.2	121,190	9.2	39,498	0.50	266	0.30	382	--	190	-0.80	- 458	30.0	79,401
Western hemlock	3.0	605	--	--	.04	8	--	--	0.04	22	--	14	3.0	676
Total	46.2	121,795	9.2	39,498	0.54	274	0.30	382	0.04	212	-0.80	- 444	33.0	80,077
Willamette N. F. - No. 9														
Douglas-fir	79.0	136,843	25.4	51,411	0.06	62	0.14	28	--	305	-0.20	215	52.6	86,510
Western hemlock	2.7	1,838	--	--	--	--	--	--	--	3	--	3	2.7	1,853
Western redcedar	17.6	8,640	8.3	2,184	--	--	.06	9	--	--	- .06	- 9	9.0	6,409
Total	99.3	147,321	33.7	53,595	0.06	62	0.20	37	--	308	-0.26	209	64.3	94,772
	Reserve stand 5 years after cutting 1/				Second 5 years								Reserve stand 10 years after cutting	
Willamette N. F. - No. 6														
Douglas-fir	10.5	39,339			0.04	9	--	--	--	34	0.04	25	11.0	39,463
Western hemlock	30.0	10,745			.36	67	0.10	62	--	160	--	31	29.7	10,900
Western redcedar	12.2	7,092			.04	56	.04	9	--	73	.26	8	13.5	7,131
Total	52.7	57,176			0.44	132	0.14	71	--	267	.30	64	54.2	57,494
Willamette N. F. - No. 7														
Douglas-fir	13.0	78,423			0.12	993	0.06	415	--	5	-0.20	-1,403	12.0	71,406
Western hemlock	21.0	19,467			.34	626	--	--	--	222	.26	- 404	22.3	17,446
Western redcedar	2.3	4,233			--	--	--	--	--	2	.08	2	2.7	4,246
Total	36.3	102,123			0.46	1,619	0.06	415	--	229	0.14	-1,805	37.0	93,098
Willamette N. F. - No. 9														
Douglas-fir	52.3	83,477			--	--	0.06	36	--	347	-0.06	311	52.0	85,030
Western hemlock	2.3	1,901			--	--	--	--	--	33	.06	33	2.6	2,064
Western redcedar	7.4	6,763			0.06	13	.08	42	--	39	- .08	- 16	7.0	6,683
Total	62.0	92,141			0.06	13	0.14	78	--	419	-0.08	328	61.6	93,777

1/ After the first 5 years, there was some adjustment in plot boundaries and numbered trees. For that reason, the first 2 columns in the second 5-year record do not always agree with the last 2 columns in the first 5-year record above.

10 inches in diameter were destroyed. Of a total of 52 trees per acre in the reserve stand, 14 were injured by logging and 38 were uninjured. The 52 trees had a total volume of 58,000 board feet per acre. Windfall and some other mortality resulted in a net loss of about two small trees per acre at the end of 5 years (9 board feet per acre per year) on this plot.

During the second 5 years, growth rate increased slightly and mortality declined, so that there was a net increment of 64 board feet per acre per year for this period.

Young Douglas-firs in the stand that had come in after the fire of some 85 years ago were tall, slender, and clean boled; after partial cutting there was some loss among them continually from windfall or snowbreak. The hemlock understory was mostly defective and of bad form, and more than one-fourth of the trees were injured in logging; they were certainly undesirable as a reserve stand. The cedar was thrifty and appeared to be an excellent reserve component, but within 2 years it was heavily attacked by the western cedar borer, and those cedars large enough had to be cut for poles.

Except in concentrations of old-growth Douglas-fir and places where single old-growth trees could be picked out without disturbance, this stand should have been left intact until understory trees reached merchantable size.

Decadent Old Growth With a Light Understory

Plot No. 7, a heavier stand on a slightly better site, supported a stand of 159,000 board feet per acre gross volume of highly defective old-growth, mostly Douglas-fir. Nine large Douglas-fir trees per acre were cut, and about 6 small hemlock and cedar trees per acre were destroyed in logging; their combined volume was 54,000 board feet. This stand was untouched by the fire that had burned plot No. 6. As a result, the understory had no Douglas-firs and only a few hemlocks and cedars of a younger age class. Growth of living trees at the end of the first 5-year period after cutting was 256 board feet per acre per year, but mortality from windfall and other causes was sufficiently great to show a loss of 660 board feet per acre per year for the period. In the next 5 years, the growth rate remained about the same, but windfall increased sharply so that the area showed a net loss of 1,805 board feet per acre per year.

Another distressing fact on this area was the nature of the reserve stand. Mostly sound trees were cut. The reserve stand of more than 100,000 feet per acre was only 20 percent in completely sound trees, and about half of the volume was in completely cull trees. Also, about a quarter of the reserve trees were injured, tending in time to increase the percent of cull. Even though individual tree mortality should decline or cease entirely, decay will increase because of logging injury, and the stand will continue to go backward. It appears that this area should have been clear cut.

Pure Old-Growth Douglas-Fir

Plot No. 8 was similar to plot No. 7, but was more nearly pure Douglas-fir. Of an original stand of 122,000 board feet per acre, 9 trees, about 39,000 feet, were cut. About a fifth of the reserve trees were injured in logging. In the first 5-year period, growth on trees left alive was slightly more than 200 board feet per acre per year, but mortality from windfall and other causes more than offset the growth. The net loss was 444 board feet per acre per year. One of the 4 acres in this area showed a slight gain, the other 3 showed substantial losses. The 10-year record was not available.

Thrifty Middle-Aged Stand of Pure Douglas-Fir

Plot No. 9 was in a mature but thrifty stand of Douglas-fir between 150 and 175 years old except for a few older wolf trees. The stand was dense, the boles were well cleared, and the trees showed no evidence of decay, but they were growing very slowly. Gentle topography and favorable stand conditions offered an opportunity to make a partial cut that should have resulted in accelerated growth of high-quality material on clear boles in the reserve stand. Care was used in marking to leave good trees well distributed over the area, but the wolf trees were not taken because they were in large openings.

Slightly more than a third of the original stand of 147,000 board feet per acre was removed in the cut. The reaction of this stand to partial cutting was disappointing, for growth continued to be slow after cutting. Bark sloughed off or knocked off by logging caused d.b.h. measurements to show no diameter growth in the first 5 years. Increment borings, however, showed that growth accelerated slightly; the average annual d.b.h. growth before cutting was 0.04 inches, after cutting nearly 0.05. Gross growth was 308 board feet per acre per year. The net growth was 209 feet,

which is low for this well-stocked Douglas-fir stand that had made rapid growth in earlier years. About a third of the trees in the reserve stand were injured by logging. But injuries were slight and were practically all on Douglas-fir, and for that reason were considered not very damaging as Douglas-fir is not highly subject to decay following injury.

Losses remained about the same for the second 5-year period, but there was a slight increase in growth rate. The net growth per acre per year was 328 board feet--still far below the average annual growth (of 840 board feet per acre) for the plot during the life of the stand.

Summary of West Central Oregon Cascade Forests

All of these plots were on favorable topography. About a third of the stand was harvested (mostly from sound trees). A few trees per acre in the smaller diameter classes were killed and about a third of the reserve stand injured by logging. Even after cutting, all plots were still more than fully stocked, although cutting made for a somewhat uneven spacing. One stand (plot No. 9) was middle aged, thrifty, and sound; the other three were overmature and decadent, one of these (plot No. 6) having patches of 85-year hemlock and Douglas-fir and a well-developed understory.

Five years after logging all three of the overmature areas showed a loss in both number of trees and volume. It amounted to more than the current growth; in fact, there was an average net loss of 371 board feet per acre per year. And this does not include progress of decay or trees killed by logging. Losses continued during the 5- to 10-year period after logging. There is no indication that losses had subsided, but even if they had, it will take many years' growth to regain the volume already lost.

The thrifty, middle-aged stand was confidently expected to respond to a partial cut, but the acceleration of growth was disappointingly slight. Since the reserve stand is still heavily stocked, it is probable that a second cut will be necessary to produce any substantial increase in growth. But this plot did show a net increment and very little loss from windfall or other causes. Stands of this nature, where growth is on clear boles of sound trees, may offer real promise for a partial or release cutting, or may even be windfirm enough to allow a regeneration cut before a final or harvest cut is made. However, there was already considerable brush development that would hamper restocking.

Northern Oregon Cascade Forests

Two groups of sample plots representing different conditions were established on each of two different localities on the Mt. Hood National Forest (table 6). One group, plots 6 and 7, was near Parkdale on a dry site east of the Cascade summit and near the transition zone from Douglas-fir to ponderosa pine. The other group, plots 8 and 9, was on Clear Creek on the west slope of Mt. Hood in a more typical west-side forest.

A High, Dry Site

The east-side stand was between 150 and 175 years old and comparatively sound, but for some time, trees had been dying here and there from insect attack, drought, or some other cause.

Plot 6 had an original gross volume of 93,000 board feet per acre, almost entirely Douglas-fir, from which about one-third was cut or destroyed in logging. About 29 percent of the reserve trees sustained logging injuries. An effort was made on this area to mark the low-vigor and badly formed trees for cutting. Growth was about 370 board feet per acre per year, but mortality from windfall and other causes was sufficient to offset growth and cause a net loss of 240 board feet per acre per year for the 5-year period.

Plot 7 was similar to plot 6 except that it contained a heavier mixture of grand fir. It was given a much lighter cut, 17,000 feet, or 18 percent of the gross volume of 94,000 board feet per acre. Growth on this plot amounted to 680 board feet per acre per year. But mortality nearly offset this good growth rate. The 5-year period ended with a net gain of 63 board feet per acre per year. Spot burning for brush disposal was responsible for some of the mortality. Brush burning injury plus logging damage to the living reserve brought the injury figure up to 49 percent of the trees.

At the time of cutting, the stand on both plots showed evidence of low vigor with dead and dying trees. It was hoped the cut would salvage these dead and dying trees and restore the stand to a thrifty condition. The plots had an average reserve stand of nearly 70,000 board feet per acre. The reserve trees did appear more healthy at the end of 5 years, but mortality had not ceased, and the extremely slow diameter growth had accelerated so little (0.003 inch) that it was hardly measurable. Later cuts may result in accelerated growth. Visible benefits from this cut were

Table 6.--Original stand and cut, with annual mortality, gross growth, and net increment during first 5 years in Northern Oregon Cascade areas. (Per-acre values are given by species in number of trees and Scribner volume.)

Plot location and species	Original stand		Cut or destroyed		First 5 years								Reserve stand 5 years after cutting	
					Annual mortality and gross growth						Annual net increment			
					Mortality				Gross growth					
					Windfall		Other							
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Grose volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per eore	Per acre	Bd. ft. per ecre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Mt. Hood N. F. - No. 6														
Douglas-fir	88.0	91,602	26.7	31,440	0.26	217	0.40	254	--	362	-0.66	-109	58.0	59,618
Grand fir	1.3	1,131	--	--	.06	140	--	--	--	9	- .06	-131	1.0	474
Total	89.3	92,733	26.7	31,440	0.32	357	0.40	254	--	371	-0.72	-240	59.0	60,092
Mt. Hood N. F. - No. 7														
Douglas-fir	74.3	84,471	16.3	17,128	0.20	69	0.40	171	--	558	-0.60	318	55.0	68,935
Grand fir	8.3	9,427	--	--	--	--	.26	381	--	126	- .26	-255	7.0	8,150
Total	82.6	93,898	16.3	17,128	0.20	69	0.66	552	--	684	-0.86	63	62.0	77,085
Mt. Hood N. F. - No. 8														
Douglae-fir	17.3	88,962	6.3	32,363	--	--	--	--	--	121	--	121	11.0	57,202
Western hemlock	26.6	59,888	2.3	6,445	--	--	--	--	--	129	--	129	24.3	54,086
Western redceder	1.4	7,353	.7	1,663	--	--	--	--	--	25	--	25	.7	5,817
Silver fir	12.3	4,742	3.0	361	--	--	0.06	16	--	42	-0.06	26	9.0	4,511
Total	57.6	160,945	12.3	40,832	--	--	0.06	16	--	317	-0.06	301	45.0	121,616
Mt. Hood N. F. - No. 9														
Douglas-fir	12.5	39,469	5.0	17,888	--	--	--	--	--	139	--	139	7.5	22,277
Western hemlock	31.5	52,815	.5	1,027	--	--	--	--	--	317	--	317	31.0	53,371
Western redceder	2.0	2,890	1.0	1,708	--	--	--	--	--	--	--	--	1.0	1,180
Silver fir	37.0	10,683	1.5	146	--	--	--	--	0.10	128	0.10	128	36.0	11,177
Western white pine	1.5	2,161	--	--	--	--	--	--	--	10	--	10	1.5	2,213
Total	84.5	108,018	8.0	20,769	--	--	--	--	0.10	594	0.10	594	77.0	90,218

the harvesting of the dead and dying trees and the leaving of clear boles for the addition of new growth. The crowns were not dense, and it was hoped that Douglas-fir regeneration would follow this cut. Some Douglas-fir seedlings did occur in the largest openings, but they are low in vigor. There is, however, a thrifty stand of grand fir and brush coming in. They will probably gain possession of the understory.

A Watershed Cutting in Overmature Douglas-Fir

Plots 8 and 9 (table 6) differed from all other areas studied in that they were in an auxiliary watershed for the City of Portland water supply in the Bull Run Division of the Mt. Hood National Forest. For that reason, the objective in marking was different from that on other cuttings, and more care was taken in the logging operation so as to minimize watershed disturbance. The cutting was light, and only such trees were taken as would not greatly break the crown canopy or cause a heavy accumulation of slash on the forest floor.

Plot No. 8 consisted of a heavy, old-growth stand of Douglas-fir and hemlock with a light mixture of Pacific silver fir and cedar. Trees were mostly large. The original stand had a total of 161,000 board feet per acre, from which 41,000 were removed. Logging injured 38 percent of the reserve stand. But windfall and other mortality for the first 5-year period were practically negligible. Gross growth of living trees amounted to 300 board feet per acre per year for the period.

Plot 9 was part of the same general stand. But there, many of the large, old trees had disappeared from various causes years ago and had been replaced by small understory hemlock and other tolerant species. Hemlock predominated before cutting; and because mostly Douglas-fir was cut, Douglas-fir made up less than one-fourth of the stand after cutting. Of the 108,000 board feet per acre in the original stand, 21,000, or 19 percent, were cut. A third of the reserve stand sustained some injury during logging. Growth on this plot was practically double that on the previous one, probably because of the small number of large old trees and high number of young tolerant trees in the lower diameter classes. It amounted to nearly 600 board feet per acre per year during the 5-year period. There was no windfall or other mortality on the plot during this 5-year period.

Both plots 8 and 9 showed a net gain for the first 5 years after logging, and the lowest mortality of any of the 15 areas studied. However, no deduction was made for the living decadent trees in the stand or for the acceleration of decay that will result from the logging injury sustained (9). This current decay will greatly reduce the annual gross growth shown for these plots. The aim of this cutting was to harvest part of the crop with the least possible watershed disturbance or increase in fire hazard. For example, large defective hemlocks with big bushy crowns were not taken. Inferior trees were taken only if their crowns were small, and they could be removed without great disturbance. Although light successive cuts of this nature may not favor maximum timber production, the operation does indicate that they are feasible in this timber and soil type, if watershed protection is the primary objective. If the cuts were repeated, the Douglas-fir would soon be eliminated from the stand. The older and more overmature hemlocks and other tolerant species would die or be cut next. If natural succession were not interrupted by windfall or some other catastrophe, a climax forest of hemlock, cedar, and silver fir should develop, which should be satisfactory for watershed purposes (6).

Northern Washington Forests

Old-Growth Douglas-Fir With Heavy Mixture of Cedar

One area studied (Mt. Baker permanent sample plot 2) lies on Dan's Creek above Darrington, Washington. It is typical of the overmature stands of Douglas-fir in the middle elevations of the northern Cascades, except that it had more than the usual amount of western redcedar at the time of cutting. It consisted of very large, scattered, old-growth Douglas-fir and cedar trees with a well-developed understory of western hemlock, silver fir, and western redcedar in all age classes.

The purpose of the cut was to remove the old overmature Douglas-firs and cedars and leave the understory of hemlock, cedar, and silver fir for further growth and later cutting. The original forest had a volume of 109,000 board feet per acre from which 43,000 feet, or 40 percent of the gross volume, were removed by the cut (table 7).

During the first 5 years after logging, gross growth averaged 837 board feet per acre per year on trees alive at the end of the period. But losses from windfall and other causes were great

Table 7.--Original stand and cut with annual mortality, gross growth, and net increment during first and second 5 years in northern Washington areas.
(Per-acre values are given by species in number of trees and Scribner volumes.)

Plot location and species	Original stand		Cut or destroyed		First 5 years: Annual mortality and gross growth: Mortality: Windfall		Other		Gross growth		Annual net increment		Reserve stand 5 years after cutting	
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Mt. Baker N. F. - No. 2														
Douglas-fir	2.2	25,552	1.7	21,490	--	--	--	--	--	3	--	3	0.5	4,074
Western hemlock	87.5	17,774	25.8	2,356	0.14	28	0.30	230	--	365	-0.44	107	59.5	15,956
Western redcedar	27.2	58,454	6.2	17,695	.10	316	.02	60	--	375	- .12	- 1	20.4	40,754
Silver fir	20.4	7,346	6.0	1,738	--	--	.24	9	--	94	- .24	85	13.2	6,032
Total	137.3	109,126	39.7	43,279	0.24	344	0.56	299	--	837	-0.80	194	93.6	66,816
Olympic N. F. - No. 17														
Douglas-fir	34.2	119,740	10.2	34,030	1.20	5,341	--	--	--	353	-1.20	-4,988	18.0	60,768
Western hemlock	19.2	22,096	3.8	5,922	.44	557	--	--	--	210	- .44	- 347	13.2	14,443
Western redcedar	31.5	15,465	4.5	2,980	.86	1,018	--	--	--	85	- .86	- 933	22.7	7,820
Total	84.9	157,301	18.5	42,932	2.50	6,916	--	--	--	648	-2.50	-6,268	53.9	83,031
Olympic N. F. - No. 18														
Douglas-fir	0.7	9,910	0.5	9,750	--	--	--	--	--	8	--	8	0.2	200
Western hemlock	39.0	32,334	4.2	2,365	0.64	261	0.20	220	0.24	410	-0.60	- 71	31.8	29,610
Western redcedar	8.3	51,819	5.2	49,271	.06	11	--	--	.04	60	- .02	49	3.0	2,794
Silver fir	10.0	8,525	.5	327	.10	65	.24	151	.24	181	- .10	- 35	9.0	8,026
Total	58.0	102,588	10.4	61,713	0.80	337	0.44	371	0.52	659	-0.72	- 49	44.0	40,630
	Reserve stand 5 years after cutting				Second 5 years								Reserve stand 10 years after cutting	
Mt. Baker N. F. - No. 2														
Douglas-fir	0.5	4,074			--	--	--	--	--	9	--	9	0.5	4,120
Western hemlock	59.5	15,956			0.50	57	1.12	320	--	296	-1.32	- 81	52.9	15,552
Western redcedar	20.4	40,754			.04	--	.04	--	--	544	-0.02	544	20.3	43,473
Silver fir	13.2	6,032			.16	23	.14	146	--	122	- .20	- 47	12.2	5,798
Total	93.6	66,816			0.70	80	1.30	466	--	971	-1.54	425	85.9	68,943
Olympic N. F. - No. 17														
Douglas-fir	18.0	60,768			0.10	431	--	--	--	446	-0.10	15	17.5	60,847
Western hemlock	13.2	14,443			.04	167	0.10	100	--	220	- .10	- 47	12.7	14,209
Western redcedar	22.7	7,820			.10	63	.04	2	--	121	- .14	56	22.0	8,095
Total	53.9	83,031			0.24	661	0.14	102	--	787	-0.34	24	52.2	83,151
Olympic N. F. - No. 18														
Douglas-fir	0.2	200			0.04	40	--	--	--	--	-0.04	- 40	--	--
Western hemlock	31.8	29,610			2.56	2,259	0.24	370	--	214	-2.64	-2,415	18.6	17,532
Western redcedar	3.0	2,794			.10	143	.04	43	--	83	.10	- 103	3.5	2,280
Silver fir	9.0	8,026			.20	173	.34	152	--	123	-0.44	- 202	6.8	7,018
Total	44.0	40,630			2.90	2,615	0.62	565	--	420	-3.02	-2,760	28.9	26,830

enough to reduce the annual growth to a net gain of 194 board feet per acre per year. Growth during the second 5-year period was somewhat greater. Losses from windfall declined substantially and from other causes increased slightly, resulting in a net gain of 425 board feet per acre per year. This is one of the 2 areas out of a total of 10 that showed a net gain for both the first and second 5-year period after logging. The average for the 10-year period amounts to a net gain of 310 board feet per acre per year.

The sample area consisted of a block of six 1-acre plots located in the center of a well-protected, moderately steep slope. Growth varied within this area; 4 of the 6 acres showed a net gain at the end of the period, the other 2 a loss. In stand composition, topography, and treatment, the sample plot was typical of this large, partially cut stand, but it appeared to be exceptionally well protected from wind. Considerable windfall loss was sustained in parts of the stand outside the plot boundaries. But windfall losses were relatively low on the plot. The discrepancy illustrates the chance of error in using a single, large sample. Several well-distributed small samples would probably have shown the windfall loss.

Old-Growth Douglas-Fir Blowdown

The northern Washington area (Olympic permanent sample plot 17) was located near Cushman Lake, above Hoodsport.

This area supported a typical, heavy, old-growth stand of Douglas-fir with a light mixture of western hemlock and western redcedar. It had a total gross volume of 157,000 board feet per acre (table 7). Much of the hemlock and cedar was in the understory and was under or just approaching merchantable size.

Windfall had taken much of the old stand and some of the younger understory. Cutting was planned to salvage the windfallen material and to take out enough of the live residual stand to make the operation profitable. The cut amounted to 27 percent by volume of standing trees. Because of the tangled condition of the stand resulting from windfall, logging destroyed an estimated 2,000 feet or more to the acre. Breakage and excessive decay in the large, old trees caused many heavy chunks of broken logs and tops to be left on the ground. This debris was ideal for development of a large bark beetle population, and beetles caused heavy losses in the residual stand during logging and the first couple of years thereafter.

This unusual set of conditions resulted in the heaviest beetle and windfall loss experienced on any study area. By the time the 5-year examination was made, some beetle-killed timber had been blown down, and some dead standing and down timber had been salvaged. Therefore, losses could not be segregated, and all were listed as windfall in the table. Growth on live trees during the first 5 years after cutting was more than 600 board feet per acre per year. But the net loss during the period amounted to 6,268 board feet per acre per year.

During the second 5-year period, losses from all causes declined, and growth increased slightly (to 787 board feet). Nevertheless, losses were heavy enough that net growth was only 24 board feet per acre per year. The total net loss on this area during the 10-year period since logging amounted to 3,122 board feet per acre per year. If all losses ceased, this area would still have to grow 1,000 board feet per acre per year for the next 31 years to restore the volume it contained in the residual stand when the cutting operation was complete.

A Two-Story North Olympic Blowdown

One area (Olympic permanent sample plot 18) was located on Salmon Creek above Blyn, Washington, on the north slope of the Olympics. This area consisted of an overmature stand of widely scattered, large, old Douglas-fir and cedar with a well-developed understory consisting mostly of hemlock and Pacific silver fir. It is typical of the mixed forest on the northwest slopes of the Olympic Peninsula.

Large trees had been falling intermittently on this area for many years, and after one heavier than usual windfall in the early 1930's, salvage cutting was planned for the area. The plan was to take out salvable windfalls and part of the reserve stand. The understory stand on this tract was sufficient to make a well-stocked, new forest provided the logging would not seriously damage the reserve stand or open it enough to accelerate windfall. The windfalls and about one-half of the living trees, large and small, were removed.

Growth was about 650 board feet per acre per year on the trees alive 5 years after cutting. But losses from windfall and other mortality during this period more than offset the growth. The result was an annual net loss of approximately 50 board feet per acre for the period.

Unlike most study areas, this stand did not tend to stabilize and show a reduction in mortality during the second 5-year period. Gross growth was about 400 board feet per acre per year on the reserve trees that remained alive. But the losses, mostly from windfall, were sufficiently great to show a net loss of 2,760 board feet per acre per year for the second 5-year period. The net loss for 10 years after logging amounted to 1,405 board feet per acre per year. The total loss amounted to nearly half of the total reserve after logging. The stand on part of the sample plots had been practically blown flat just before the 10-year examination was made in the fall of 1946. Shortly thereafter, the area as a whole was in such a tangled mass that a salvage clear cut was necessary.

Like the Cushman plot, this area indicates that where windfall losses have occurred, they are likely to continue. It would have been better forest management to clear cut this area in the beginning, sacrificing some of the undersized and otherwise unmerchantable material. It had to be clear cut eventually.

Summary of Northern Washington Forests

The three areas in this group are all heavy old stands with well-developed understories of tolerant species. The Mt. Baker area was on a well-protected slope and had sustained no recent unusual windfall or other losses. It survived a partial cut without abnormal loss and made a net growth in the 10 succeeding years. Successive cuts of this nature may permit many understory trees to reach a better merchantable size, but in the meantime, the average annual net growth for this area is not more than a third of what it should be on this site.

The Cushman Lake and Salmon Creek stands were sustaining heavy windfall losses before cutting. These two operations demonstrated that a salvage cut in stands of this nature, taking out windfall and other susceptible trees, did not stabilize the stands. Losses from windfall and other causes probably will continue at an accelerated pace until the stand is destroyed if not cut.

South Olympic Forests

The south Olympic areas had stands somewhat older than the others; in addition, some temporary plot work was done in the locality to supplement permanent sample-plot findings. For that reason, the permanent plots are summarized jointly (table 8).

Table 8.--Original stand and cut with annual mortality, gross growth, and net increment during first and second 5 years in South Olympic area.
(Per-acre values are given by species in number of trees and Scribner volume.)

Plot location and species	Original stand		Cut or destroyed		First 5 years							Reserve stand 5 years after cutting	
					Annual mortality and gross growth					Annual net increment			
					Mortality				Growth:				
					Windfall		Other						
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Olympic N. F. - Nos. 22,23,24													
Douglas-fir	7.6	99,458	4.7	64,671	0.02	181	--	--	14	-0.02	-167	2.8	33,951
Western hemlock	38.8	54,962	7.2	8,120	.04	51	0.68	984	396	- .72	-639	28.0	43,649
Western redcedar	1.3	8,366	.1	12	--	--	--	--	25	--	25	1.2	8,480
Total	47.7	162,786	12.0	72,803	0.06	232	0.68	984	435	-0.74	-781	32.0	86,080
	Reserve stand 5 years after cutting 1/				Second 5 years							Reserve stand 10 years after cutting	
Olympic N. F. - Nos. 22,23,24													
Douglas-fir	2.6	30,355			0.02	221	--	--	- 82	-0.02	-303	2.5	28,841
Western hemlock	29.7	43,670			.06	55	0.24	702	803	- .34	46	31.4	43,900
Western redcedar	1.2	8,496			--	--	--	--	3	--	3	1.2	8,512
Total	33.5	82,521			0.08	276	0.24	702	724	-0.32	-254	35.1	81,253

1/ At the end of the first 5-year period, there was some adjustment in plot boundaries and numbered trees. This fact accounts for the difference in the reserve stand at the end of the first 5 years and the beginning of the second.

Douglas-Fir Stand More Than 500 Years Old in Transition Stage

Each of these three groups of sample plots (Olympic permanent sample plots 22, 23, and 24) represented somewhat different conditions before cutting, but they were sufficiently similar to permit averaging. The plots are located on the south slopes of the Olympic Mountains in an area of high rainfall and a good site. The virgin forest here was old--for the most part more than 500 years. Douglas-fir trees remaining from this old forest were very large and, for their age, were comparatively sound. Tolerant cedar and hemlock had come in and made up an understory as the old, intolerant Douglas-firs died (6). The 3 groups of sample plots, embracing a total of 10 separate 1-acre plots, had an average gross volume before cutting of 163,000 board feet per acre (table 8). Forty-five percent, or 73,000 board feet, was taken out, usually the largest and best trees that were often more than 60 inches in diameter. In the process of logging, more than half of the reserve stand received some logging injury at the base, bole, or crown, and sometimes in more than one place on the same tree. Growth of living trees during the 5 years after the cutting operation amounted to 435 board feet per acre per year. This is a low growth rate for a high site, but is understandable when the age of the stand (500 years) and the density of the reserve are considered. After cutting, the stand was 90,000 board feet to the acre.

Mortality was light from windfall loss, but heavier from other causes in the first 5 years after logging. Eight of the 10 acres showed a net loss at 5 years. The mortality averaged 1,216 board feet per acre per year for this period. It was sufficiently high to offset the growth and cause a net loss of 781 board feet per acre per year.

Growth increased from 435 board feet in the first 5-year period to 724 board feet per acre per year in the second. Yet current mortality was sufficient in the second 5-year period to result in a net loss of 254 board feet per acre per year. In future years, mortality resulting from logging injury and exposure might be expected to decline or to cease altogether, but losses from windfall and other causes are rather certain to continue. The average annual net loss was 517 board feet per acre per year for the first 10 years after cutting. No record is available of losses in natural uncut stands of this character in the immediate locality; therefore, it is impossible to evaluate accurately this loss. However, the loss positively establishes the fact that the partial cut in this stand

did not restore it to a thrifty growing condition that would result in an annual volume increase.

These permanent sample plots were located on one of the larger national-forest timber-sale areas. To determine if they were representative of the area as a whole as to percent of cut, injury, and losses, additional strip surveys were run in several other parts of the area. Also, temporary plots were established on parts of the area to measure the effect of a second and third cut. These temporary plot records were summarized but are not presented in tabular form.

Temporary Plot Record of Similar Adjoining Stand

A summary of the strips on the area that had been once cut over showed that an average of one-fourth of the volume was removed from an original stand of 96,000 board feet per acre. Included in the amount cut were a few trees that were destroyed by logging. The cutting left a reserve stand of 69,000 feet gross volume per acre, 47,000 of which were hemlock, mostly understory. The uncut Douglas-fir was fairly sound, but the hemlock was not. It was estimated that the hemlock was more than 25 percent defective (by volume). Thirty-five percent of the reserve stand received some sort of logging injury. Some of these injured trees were already decadent, and some of the uninjured reserve trees were also decadent. It was estimated that only about 50 percent of the volume of the reserve stand was in trees that were free from both logging injury and decay. The areas were cut in 1940 and re-examined in 1944. During this 4-year period of time, mortality averaged four trees per acre, mostly hemlock. This resulted in a net periodic loss of 2,600 board feet per acre, or about 650 board feet per acre per year. Although these strip surveys were in somewhat lighter stands with a higher percentage of hemlock, they indicate that cut, injury, and losses on the rest of the partially cut area were quite similar to those reported on the three permanent sample plots. The permanent sample plots may therefore be considered valid samples.

Effect of Second Cut on a Similar Adjoining Stand

In order to measure the effect of a later cut on these stands, the timber-sale administrators decided to make a second cut on one part of the tract. This was done in 1944. The original cut was made in 1939. The amount taken out in the first and second cuts plus a

small amount destroyed by the logging operation amounted to approximately 40 percent of an original stand of 86,000 board feet per acre. Mortality for the 5-year period was approximately 1,000 board feet per acre per year. The skidding on this area was done primarily by tractors. On a few steeper localities, logs were hauled on a contour by tractors to a high line and taken out by the high line. Therefore, most of the logging injury resulted from the skidding by tractors. Originally, it was anticipated that trees injured in the first cut could be removed in the second cut. It was expected that because the forest would be more open, the second cut would result in less injury than the first. However, this did not work out in practice. Many of the injured trees were below merchantable size, and no additional trees could be removed from this heavy, old-growth forest without additional injury to the reserve. At the end of the first cut, 35 percent of the reserve stand was injured. Although as many of these injured trees as possible were taken out, after the second cut 54 percent of the remaining trees showed logging injury when the operation was completed. It was estimated that 16 percent of the uninjured reserve trees had some decay and that a similar percentage of the injured trees had decay in addition to the logging injury. The second cut, then, left a reserve stand of about 50,000 board feet per acre, only 30 percent of which was in sound, uninjured trees.

Effect of Third Cut on a Similar Adjoining Stand

To give further information on the effect of successive cuts in a heavy stand of this nature, it was decided to make a third cut on one area immediately after the second cut was completed. Normally, a third cut would have been deferred several years. This area had an original stand of 92,000 board feet per acre, one-seventh of which was old-growth Douglas-fir in large trees. A quarter of the stand had been removed 5 years previously in a first cut. The equivalent of two more quarters was removed in the second and third cuts, taking out a total of 68,000 feet, or approximately 74 percent of the stand. The recorded mortality during the first 5-year period, plus a few trees killed in logging, amounted to 4,800 board feet per acre, or more than 900 board feet per acre per year. When the third cut was finished, practically all trees more than 20 inches in diameter were gone, including all Douglas-firs. This left a reserve stand of 36 live trees per acre, 86 percent injured or defective, or both.

It was anticipated that reproduction would become established after early cuts, though perhaps of the less desirable, tolerant

species. But a dense forest of large trees is greatly disturbed by logging, and most of the reproduction that became established on this area after the first cut was destroyed or injured by the second or third cuts. A record of surface conditions showed that in the 3 operations combined, 94 percent of the original forest floor was either disturbed by logging or had logging debris piled upon it. Seventy-one percent of the surface was affected in the final two cuts. Here reproduction was destroyed; on the small undisturbed surfaces it was overly dense--an extremely patchwise and unsatisfactory pattern of natural regeneration. If the 36 reserve trees survive, a stand of hemlock reproduction may yet become established.

Summary of South Olympic Areas

The selectively cut, old-growth forest in the south Olympics was sampled by three groups of permanent sample plots to measure the amount cut, injury, current mortality, and growth. They were supplemented by temporary plots for further checks of injury and mortality several years after logging. On a part of this area second and third partial cuts were also made and their effects on the stand recorded.

From 35 to 50 percent of the reserve stand on both the permanent plots and the other plots sustained logging injury. The permanent plots for the first 5 years after cutting showed a net loss of 781 board feet per acre per year; mortality on the other plots was approximately the same Losses declined on the permanent plots in the second 5-year period but did not cease. Annual net loss for the 10-year period was 517 board feet per acre.

The second cut revealed it was not feasible to remove all trees injured in the first operation because many trees were too small; in fact, the second cut increased the injury to the reserve stand to a total of 54 percent. A third cut was still more detrimental to this stand. It increased the amount removed to 74 percent of the original forest, eliminated the Douglas-fir, and left an inferior stand of small hemlock trees, most of which had developed in the understory. Thirty-six live trees per acre were left, 86 percent of them injured or defective, or both.

Both permanent and temporary plots in this stand indicate that partial cutting has not produced favorable results. Attempts at second and third cuts made conditions worse instead of better.

Mortality on permanent plots was so great for the first 10 years that if all losses ceased at the end of that period another 10 years would be required at the current growth rate to restore past losses. In other words, 20 years after cutting, the reserve stand would again contain the volume it had when the first partial cutting operation was finished.

Old-Growth Fog Belt Forests

One area sampled was typical of the overmature fog belt forests of Douglas-fir with much hemlock and spruce and some western redcedar in mixture. This area is south of Quinault Lake in Washington, on a broad flat that is low and moist, except for a few well-drained low ridges and knolls. Once the forest probably contained a somewhat uniform mixture of all four species, but the distribution changed as the forest advanced in age to its 500-year-old stage of overmaturity at the time of cutting. Douglas-fir appeared to have persisted in greater numbers on the better drained sites, the cedar on the more moist sites, and spruce and hemlock on the sites with average drainage. For many years since the stand reached maturity the very large, old trees have been dropping out, to be replaced by an understory of the more tolerant species in all age classes (6). In some places, the old stand is still fairly intact; in others, only scattered, old trees remain. The existing stand presents three different compositions, and for that reason, three sample blocks were selected, each consisting of five 1-acre plots.

The first block of sample plots was representative of stands in which only spruce and hemlock trees remain--some veterans of the original forest, and the rest understory trees that filled in the stand as the years passed. The second group of sample plots was representative of stands containing a mixture of Douglas-fir, western hemlock, and western redcedar, but no Sitka spruce. The third group of sample plots represented stands with a few large, old Douglas-fir and spruce, a heavy stand of understory hemlock, and a very light mixture of western redcedar.

An attempt was made to restore this forest to a degree of thrift by taking out a few of the remaining old trees. The percent of cut varied, depending primarily on how many large, old Douglas-fir or Sitka spruce were available for cutting.

The sale was made and the sample plots established in 1936, but at first the cutting was only for right-of-ways and landings.

Eventually the actual cutting began but was not completed until 1940. Therefore, growth and losses for the first five years do not represent values for a full five-year period after logging except on a very small area where the first cutting took place.

The Spruce-Hemlock Stand

The spruce-hemlock stand was only moderately heavy (127,000 board feet per acre), and only a very light cut of large, old spruce was made. It amounted to less than 20 percent of the gross volume (table 9, plot 19). Since the stand contained a large number of trees in the small age classes and only a light cut was made, the gross growth on these plots was good; about 1,100 board feet per acre per year for living trees at the end of the first 5-year period. But windfall and mortality from other causes was so great that the tract showed a net loss of 170 board feet per acre per year.

During the next 5 years, gross growth again was high, averaging about 1,000 board feet per acre per year. Losses subsided somewhat, but they were still high enough to result in a net gain of only 270 board feet per acre per year for this second 5-year period.

Thus, in spite of the light cut and large number of trees in the younger age classes, losses were sufficiently high to reduce net gain to 50 board feet per acre per year for the 10-year period after the beginning of logging.

Scattered Old Douglas-Fir and Cedar with Hemlock Understory

This three-species stand contained 170,000 board feet to the acre (table 9, plot 20). About 59,000 board feet were removed by cutting. The cut consisted mostly of very large Douglas-firs. Gross growth on this area for the first 5-year period averaged only 500 board feet per acre per year, less than half that of the spruce-hemlock stand. Mortality was so heavy that the group of sample plots showed a net loss of 3,100 board feet per acre per year for the first 5-year period after cutting started.

Gross growth during the second 5-year period was even less, averaging only 340 board feet per acre per year, and losses continued high. The 5-year period ended with an average net loss of 2,430 board feet per acre per year.

The average annual loss for the 10-year period was 2,756 board feet per acre for this group of sample plots.

Table 9.--Original stand and cut with annual mortality, gross growth, and net increment during first and second 5 years in fog-belt area.
(Per-acre values are given by species in number of trees and Scribner volume.)

Plot location and species	Original stand		Cut or destroyed		First 5 years								Reserve stand 5 years after cutting	
					Annual mortality and gross growth						Annual net increment			
					Mortality				Gross growth					
					Windfall		Other							
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Olympic N. F. - No. 19														
Western hemlock	27.2	36,100	0.2	182	0.48	587	0.28	253	0.40	451	-0.36	- 389	25.2	33,971
Sitka spruce	26.0	91,300	3.2	21,539	.04	72	.32	430	--	721	- .36	219	21.0	70,856
Total	53.2	127,400	3.4	21,721	0.52	659	0.60	683	0.40	1,172	-0.72	- 170	46.2	104,827
Olympic N. F. - No. 20														
Douglas-fir	7.2	121,809	2.6	54,773	0.16	2,484	--	--	--	64	-0.16	-2,420	3.8	54,937
Western hemlock	22.8	41,884	1.6	2,405	.24	526	0.64	572	0.24	409	- .64	- 689	18.0	36,033
Western redcedar	1.0	6,711	.2	1,760	--	--	--	--	--	28	--	28	.8	5,090
Total	31.0	170,404	4.4	58,938	0.40	3,010	0.64	572	0.24	501	-0.80	-3,081	22.6	96,060
Olympic N. F. - No. 21														
Douglas-fir	5.2	98,466	2.8	61,964	0.08	1,628	--	--	--	34	-0.08	-1,594	2.0	28,530
Western hemlock	32.4	36,248	1.4	2,422	.40	970	1.96	1,944	0.20	365	-2.16	-2,549	20.2	21,081
Sitka spruce	5.4	40,164	2.2	21,755	.08	556	.12	241	--	106	- .20	- 691	2.2	14,954
Western redcedar	.4	2,086	--	--	--	--	--	--	--	12	--	12	.4	2,150
Total	43.4	176,964	6.4	86,141	0.56	3,154	2.08	2,185	0.20	517	-2.44	-4,822	24.8	66,715
	Reserve stand 5 years after cutting				Second 5 years								Reserve stand 10 years after cutting	
Olympic N. F. - No. 19														
Western hemlock	25.2	33,971			0.12	135	0.08	114	--	409	0.24	160	26.4	34,772
Sitka spruce	21.0	70,856			.08	173	.16	295	--	579	- .24	111	19.8	71,408
Total	46.2	104,827			0.20	308	0.24	409		988	--	271	46.2	106,180
Olympic N. F. - No. 20														
Douglas-fir	3.8	54,937			0.08	646	--	33	--	33	-0.08	- 646	3.4	51,710
Western hemlock	18.0	36,033			.12	387	0.56	1,694	--	289	- .20	-1,792	17.0	27,068
Western redcedar	.8	5,090			--	--	--	11	--	19	--	8	.8	5,130
Total	22.6	96,060			0.20	1,033	0.56	1,738	--	341	-0.28	-2,430	21.2	83,908
Olympic N. F. - No. 21														
Douglas-fir	2.0	28,530			--	--	--	88	--	--	--	- 88	2.0	28,089
Western hemlock	20.2	21,081			--	--	0.56	736	--	305	-0.24	- 431	19.0	16,927
Sitka spruce	2.2	14,954			0.04	230	.04	81	--	43	- .08	- 268	1.8	13,616
Western redcedar	.4	2,150			--	--	--	--	--	8	--	8	.4	2,188
Total	24.8	66,715			0.04	230	0.60	905	--	356	-0.32	- 779	23.2	62,820

Scattered Old Douglas-Fir and Spruce with Hemlock Understory

The gross volume of this stand was 177,000 board feet per acre, from which 86,000 board feet, or about half of the volume, was removed (table 9, plot 21). The cut was mostly Douglas-firs. During the first 5-year period, growth amounted to about 500 board feet per acre per year. But losses from both windfall and other causes were heavy, and the period ended with a net loss of 4,800 board feet per acre per year.

In the next 5 years, growth fell off somewhat, dropping to 350 board feet per acre per year. Losses also were lower, so that the average annual net loss was 780 board feet per acre per year. For the 10-year period, the net annual loss was 2,800 board feet per acre.

Summary of Old-Growth Fog Belt Forests

The three different conditions of stand composition in the fog belt were subjected to partial cuts which varied from 17 percent of the volume on the spruce-hemlock plots to 49 percent on the 4-species plots. All areas showed losses. The areas having the highest volume in large old-growth trees had the heaviest losses. Strangely enough, both in the first and second 5-year periods, the losses were not entirely from windfall. Many of the old trees died standing, and others showed signs of dying from the top down. There was no way to identify the cause of this loss positively. A most probable cause is the sudden increase in exposure of tree crowns in the reserve stand, but proof is lacking. Losses were heaviest on the area where percentage of large, old trees was highest and cutting was heaviest, but considerable loss also occurred on that part of the area with fewer large, old trees.

Mortality declined in the second 5-year period, but losses by no means stopped. A check of individual acres showed that one-third of the acres made a net gain in the first 5 years, and two-thirds showed a loss. Similar results occurred in the second 5-year period although the losses were not so heavy.

Average annual net loss for these 3 fog belt stands over the entire 10-year period was 1,830 board feet per acre. The spruce-hemlock plots showed a net gain of 50 board feet per acre per year, but this was far offset by the net loss in the other two stand conditions. Volume was great before cutting, and even the heaviest cut

(49 percent) left a heavy stand per acre. In the heavy residual stands, the current gross growth on the different areas varied from 340 to over 1,100 board feet per acre per year on trees alive at the end of 10 years. However, this growth was much less than the annual loss.

Scattered, overmature trees, more than 500 years old, were still common in the stand after cutting. The large trees that were windfallen or cut left such large holes in the younger residual stand that it became highly subject to windfall, sunscald injury, and other losses in the years that followed. Although mortality rate decreased during the second 5 years, there was no assurance that losses would cease. Even though losses should cease, the forest would have to grow an average of 1,000 board feet per acre per year for the next 18 years to regain the volume lost in 10 years. In other words, 28 years after logging started, the volume would once more about equal that in the reserve stand when the first cutting was completed.

After the first light windfall on this partially cut area, a salvage cut was made. Scattered windfalls and a few high-risk trees were removed, making small openings, but windfall loss increased. It was then proposed to clear cut the areas of heaviest windfall loss, but the clear cut had not been made at the time of the 10-year examination. In the small openings made by salvage cuts, a heavy stand of brush developed, which will hamper future cutting operations and retard natural regeneration.

This forest was long past maturity, and large trees had been dropping out of it for perhaps 300 years or more. There is little reason to believe that accelerating this opening-up process by a cut of one-third of the volume would restore this type of stand to a growing condition. Hemlock, spruce, and cedar are normally shallow-rooted species, and Douglas-fir, when growing on a moist site such as this, is more shallow rooted and less windfirm than usual. Therefore, it seems more logical that accelerated removal of old trees would increase windfall and other losses, and that is what happened on this area.

Young-Growth Fog Belt Forest With Scattered Old Trees

The stand composition and treatment of a young-growth stand in the fog belt was markedly different from that in other areas studied. The tract is located on Youngs River on the northern Oregon coast, and the sample consists of four 1-acre plots in a block (table 10).

Table 10.--Originel stand and cut with annual mortality, gross growth, end net increment during first and second 5 yeers in a young spruce-hemlock stend. (Per-ecre velues are given in number of trees and Scribner volume--1 eree comprising 4 acres not included in previous summaries.)

Plot location end species	Originel stand		Cut or destroyed		First 5 years: Annual mortality end gross growth: Mortality: Windfall		Other		Gross growth		Annuel net increment		Reserve stand 5 years after cutting	
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per ecre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per ecre	Bd. ft. per acre	Per ecre	Bd. ft. per acre	Per ecre	Bd. ft. per acre	Per ecre	Bd. ft. per acre	Per ecre	Bd. ft. per ecre
Clatsop - No. 5 (Young's River)														
Western hemlock	54.7	63,611	8.2	24,245	0.90	401	0.50	280	--	975	-1.40	294	39.5	40,835
Sitka spruce	25.3	23,851	1.0	1,185	.10	29	.06	7	--	540	- .16	504	23.5	25,189
Total	80.0	87,462	9.2	25,430	1.00	430	0.56	287	--	1,515	-1.56	798	63.0	66,024
	Reserve stand 5 years after cutting				Second 5 years								Reserve stand 10 years efter cutting	
Clatsop - No. 5 (Young's River)														
Western hemlock	39.5	40,835			0.14	156	0.10	34	0.04	805	0.20	615	38.5	43,909
Sitke spruce	23.5	25,189			.20	79	.04	9	--	523	.24	435	22.3	27,364
Total	63.0	66.024			0.34	235	0.14	43	0.04	1,328	0.44	1,050	60.8	71,273

In 1910, a majority of widely scattered old-growth Douglas-fir and Sitka spruce trees had been removed from a dense 50-year-old stand. This young stand was so dense that the area was still well stocked after most of the large old trees were removed. The young-growth stand, consisting of hemlock and spruce, was partially cut, a few more of the old trees taken out in 1935, and the sample plots put in at that time. If it were not for the old-growth element in the stand, the operation could be classed as a thinning rather than a partial cutting in old growth. The average age of the young stand when partially cut in 1935 was about 75 years; some of the hemlock was considerably older, and some of the spruce was considerably younger.

The cut varied from 18 to 51 percent on the 1-acre plots, and averaged 29 percent (table 10). The individual plot records showed heaviest losses and lowest growth rate for the plots with the heaviest cut. The loss from windfall was double that from other causes. Total loss from all causes was almost 500 board feet per acre per year for the 10-year period.

Increment borings showed no particular acceleration of growth after the removal of scattered old trees in 1910, but up to the 1935 cut, the spruce was making more rapid growth than the hemlock. After the 1935 cut, there was an acceleration in the growth of hemlock, but the growth of individual hemlock trees still did not equal that of spruce.

Growth of the reserve stand per year for the first 5-year period was more than 1,500 board feet per acre, and for the second, more than 1,300 board feet. In spite of considerable windfall and other mortality, annual net growth was nearly 1,000 board feet per acre for the 10-year period.

There were two large and two small Douglas-fir trees on the plots when they were established in 1935. The two large Douglas-firs were cut later. The two small Douglas-firs remain on the plots, but their volume was included with that of spruce. Except for these two small trees, the 1910 and 1935 cuts have practically eliminated Douglas-fir and greatly increased the percentage of hemlock in this stand. While the overall net growth was good, individual plot records showed that heavy partial cuts were impractical in young spruce-hemlock stands because the cutting resulted in heavy mortality from windfall and other causes and reduced the growth rate. Light cuts appeared feasible and were associated with rapid growth and no mortality.

Old-Growth Douglas-Fir With Port-Orford-Cedar Mixture

One sample of partial cutting was studied in the Port-Orford-cedar mixture, a subtype of Douglas-fir, on the Port Orford Cedar Experimental Forest (Powers, Oregon). Before the cutting the forest was a heavy old-growth stand of Douglas-fir (122,000 board feet per acre) with a 25-percent mixture of Port-Orford-cedar, and a negligible amount of hemlock in the understory. The operation differed from others in that only Port-Orford-cedar was cut. Two 4-acre plots were established. Plot No. 1 was destroyed by roadbuilding and fire by the end of the first 5-year period and therefore abandoned. Plot No. 2 was kept intact and maintained through the second 5 years after cutting (table 11).

An average of 27,000 board feet per acre was cut from the stand on plot 2. Annual growth of reserve trees was more than 500 board feet per acre during the first 5 years, but 3 large Douglas-firs died during that time. The result was an average annual net loss of 770 board feet per acre for the period. In the second 5 years, losses ceased and the trees showed accelerated growth, making an average annual net increase of over 900 board feet per acre.

There was practically no loss of Port-Orford-cedar in 10 years. Increment borings showed that 33 out of 40 cedar trees showed accelerated growth, 5 showed no change, and 2 showed a slower growth rate after cutting. Little or no Douglas-fir regeneration came in. But new Port-Orford-cedar regeneration showed up in the openings, and growth of established reproduction accelerated.

These findings indicate that if a partial cut were applied more to Douglas-fir and less to Port-Orford-cedar, the percentage of cedar in the stand would gradually increase, and Douglas-fir decrease. If further tests substantiate these findings, the partial-cutting method might well be applied in the cutting of old-growth stands if the policy is to favor Port-Orford-cedar.

PARTIAL CUTTING IN FRINGE TYPES ON SEVERE SITES

Individual tree selection or even shelterwood cutting may have a place in some of the abnormal stands or sites in this region. Douglas-fir occurs in pure stands or in mixture with ponderosa pine and other species in a somewhat all-aged forest on dry sites. In these stands east of the Cascade Range and to some extent in

Table 11.—Reserve stand after cut with annual mortality, gross growth, and net increment during first and second 5 years in Douglas-fir - Port-Orford-cedar type. (Per-acre values are given in number of trees and Scribner volume—2 areas comprising 8 acres.)

Plot and species	Reserve stand after cutting		First 5 years: Annual mortality and gross growth: Mortality: Windfall		Other		Gross growth		Annual net increment		Reserve stand 5 years after cutting	
	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume	No. of trees	Gross volume
	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre	Per acre	Bd. ft. per acre
Plot No. 1 1/												
Port-Orford-cedar	6.5	5,804	0.20	230	0.10	81	--	- 27	-0.30	- 338	5.0	4,112
Douglas-fir	18.5	18,603	.04	56	.70	755	0.04	273	- .70	- 538	15.0	15,912
Western hemlock	3.8	836	--	--	.46	87	--	19	- .46	- 68	1.5	498
Other	6.8	5,408	--	--	.50	416	.04	132	- .46	- 284	4.5	3,989
Total	35.6	30,651	0.24	286	1.76	1,339	0.08	397	-1.92	-1,228	26.0	24,511
Plot No. 2												
Port-Orford-cedar	12.0	6,605	0.04	62	--	--	0.20	60	0.16	- 2	12.8	6,591
Douglas-fir	25.0	87,538	--	--	0.16	1,216	--	430	-0.16	- 786	24.2	83,608
Western hemlock	1.7	690	--	--	.04	16	.14	34	.10	18	2.2	781
Total	38.7	94,833	0.04	62	0.20	1,232	0.34	524	0.10	- 770	39.2	90,980
	Reserve stand 5 years after cutting		Second 5 years								Reserve stand 10 years after cutting	
Plot No. 2												
Port-Orford-cedar	12.8	6,591					--	128	0.14	128	13.5	7,321
Douglas-fir	24.2	83,608					--	675	--	675	24.2	86,984
Western hemlock	2.2	781					--	112	.60	112	5.2	1,342
Total	39.2	90,980					--	915	0.74	915	42.9	95,647

1/ Plot No. 1 was destroyed after the first 5 years and is not included in the second 5-year record.

southwest Oregon and on severe sites within the region proper, moisture is the limiting factor. These stands are short, windfirm, and somewhat open; they let in enough light for some Douglas-fir reproduction to become established and grow. Sample plots were not located in these stands in this study, but partial cutting or true selection cutting in these stands was practiced with success east of the Cascade Range before this project began. There seems to be no logical reason why it would not be equally successful on the drier sites of southwest Oregon, the loose, gravelly soils of the Puget Sound region, or on severe south slopes elsewhere within the Douglas-fir region.

Douglas-fir seedlings become established best under light shade, but once established they make their best growth and development in full sunlight. Therefore, on the dry or more severe sites where trees are short and windfirm there is no reason why this species would not restock better under a light shelterwood cutting than under clear cutting. Once the reproduction is established, the overwood should be removed. This recommendation applies only to the drier, more severe sites where trees are shorter and more windfirm than usual. The shelterwood system is not now and never has been recommended by the author for average or better sites in the Douglas-fir region where stands are dense, where trees are tall and shallow rooted, and are not windfirm.

SUMMARY AND DISCUSSION

A single-tree, partial cutting system was tried under a wide range of stand conditions in the Douglas-fir region. Sample plots were established in national-forest timber sales from Darrington, Washington, to Oakridge, Oregon, to measure the effect of this type of cutting. Stands varied in age from 150 to more than 500 years. Species composition varied from pure Douglas-fir to heavy mixtures of associate species, including 2-story stands and stands with an all-aged understory.

The cut varied from less than 20 percent to more than 50, and averaged 36 percent of the virgin stand by gross volume. Merchantable trees from the oldest and largest size class were cut; they were usually Douglas-fir and the best trees in the stand.

The weighted average gross growth of reserve stands composed of trees alive 10 years after cutting was 555 board feet per acre per year, but this was more than offset by mortality. Two of 15 sample

areas showed a net gain for both the first and second 5-year periods, and 3 more showed a net gain either in the first or second period. Most Douglas-fir and Sitka spruce, usually the oldest trees, either maintained a uniform growth rate or showed a decline in the 10 years after cutting, compared to the 10 years before cutting. On the other hand, most hemlock, cedar, and silver fir showed an accelerated growth after cutting.

Annual mortality averaged 1,497 board feet per acre. The net loss 10 years after logging, then, was 941 board feet per acre per year. Some areas appeared to become stabilized during the first 5 years, but others had the heaviest losses in the second 5-year period. Windfall was the greatest single cause of loss, exceeding all others combined. If no further loss were to occur after the 10-year period, and if growth were to continue at the current rate, another 15 to 20 years would be required to restore the volume lost during the first 10 years after logging. In other words, 25 to 30 years after cutting the average reserve stand would have the same volume as it had when the cutting operation was finished. The forest would yield no net volume increase in 25 to 30 years following a partial-cutting operation.

Felling and skidding caused considerable damage to the reserve stand. Most skidding was done by the crawler-type tractor, and more than one-third of the trees received some sort of logging injury, often severe enough to retard growth and sometimes severe enough to kill the tree. A second and third cut on one area indicated that the percentage of injured trees in the reserve stand would increase with each successive light cut in these heavy old-growth forests. A large percentage of the reserve trees were hemlock, true firs, or spruce. A separate study of decay entrance after injury to these species showed that 63 percent of the logging scars had decay in them (9). Although decay was present in the original forest and no doubt was accelerated by logging injury and sunscald, no volume deductions were made for decay in the figures shown in this study. Therefore, decay losses, where they occur, will be in addition to losses shown in this report.

Analysis of results under different stand conditions reveals a trend toward change in species composition. Where Douglas-fir was present, the percentage was reduced by the cut. Sometimes the Douglas-fir was completely eliminated from the stand. Except in the largest openings, only a few Douglas-fir seedlings were reported, but none were vigorous enough to be considered well

established. Seedlings of the more tolerant species--hemlock, grand fir, silver fir, and cedar--were well established in many stands.

Sufficient time has not elapsed to determine if an all-age forest could be developed, but the records to date indicate that the percentage of Douglas-fir in the stand is reduced by this type of cut, and since no regeneration is becoming established, the species will eventually be eliminated. If an all-age forest can be developed, it will contain little if any Douglas-fir.

Since Douglas-fir is usually the oldest and largest element in a stand, it will probably be mostly taken out in the first few partial cuts. Thus, the peeler logs and other high-grade material will be eliminated long before the complete stand is removed, and the supply of this class of material will be exhausted more quickly than if the forest were harvested in small, clear-cut blocks. In other words, light successive partial cuts will quickly eliminate high-grade material from Douglas-fir forests.

The results of this study, on the whole, provide further proof of the accepted hypothesis that an intolerant tree like Douglas-fir is unsuited for a selection cutting that continuously harvests the oldest and ripest trees in an all-aged forest. Nevertheless, economic situations or silvicultural conditions (or a combination of these) may sometimes justify partial cutting or even tree-selection cutting. There were a few unusual examples on limited areas in this study where acceptable results were obtained with partial cuts. A mature but thrifty stand on the Willamette National Forest (table 5, plot 9) showed no unfavorable effect of partial cutting; growth continued on clear boles at a slightly accelerated rate for the 10-year period following the cut. In a Portland city auxiliary watershed on the Mt. Hood National Forest (table 6, plots 8 and 9) a light cut was made to remove high-value, overmature Douglas-fir. A net growth with practically no loss followed the cut, and there was no apparent impairment of watershed values; however, there was evidence that the cut increased the percent of defect in the stand and speeded up the natural transition from a high-grade forest of Douglas-fir to a lower grade forest of tolerant species. Removing old, scattered Douglas-firs and spruces and a small percentage of a 75-year-old understory of hemlock and spruce resulted in good growth and little loss (table 10) in a fog belt area. A partial cut in a mixed stand of Douglas-fir and Port-Orford-cedar showed that the cut would favor the Port-Orford-cedar element in the stand (table 10), a highly desirable silvicultural objective in the type.

A partial cut may also be employed successfully to salvage widely scattered bug-killed timber where the kill is not heavy enough in one locality or covers too large an area to justify immediate clear cutting. No area was sampled in this study where Douglas-fir was growing as an all-aged forest, or where there was evidence that an all-aged forest of Douglas-fir would develop as a result of partial cuts or any form of individual tree selection. However, Douglas-fir does grow as an all-aged forest and is being managed by selection cutting in the pine mixture types east of the Cascade Range on semi-arid sites. There seems no logical reason why it could not be managed in a similar manner in the fringe types on the drier sites in southwest Oregon, the gravel soils of the Puget Sound region, or severe, southerly exposures elsewhere in the region where moisture and shade are critical factors.

CONCLUSION

The partial-cutting system as studied and reported in this paper has not proved to be a successful method of harvesting the crop and converting the normal virgin forests of Douglas-fir to new or thrifty stands on the average or better sites in the region. Even under conditions where it appears to offer promise, it is always associated with an impending danger of an unfavorable species change or loss from windfall, insects, or a combination of causes. Therefore, any plan for partial cut or selection cut in the Douglas-fir type should include a careful study of stand conditions in advance and provision for salvage in the event of severe loss or catastrophe.

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